Volume XI: Number 3 (2000)

Human Systems IAC

GATEWAY

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CSERIAC Gateway classic covers.

Classic *Gateway*: A Special Issue

Michael Fineberg, Ph.D.

Words from the Chief Scientist

It is with great pride that Human Systems IAC presents its first classic edition. We have carefully selected four articles for your reading pleasure, culled independently from our past issues by the Human Systems IAC Chief Scientist, Director, and Government Technical Manager. Those with the most votes were then sent forward to the Chief Scientist of the U.S. Air Force Research Laboratory Human Effectiveness Directorate for his selection of the "final four." Each article is, in its own right, a classic; that is, a timeless piece of information that will be as useful today as when it was written.

The first article is entitled "Integrating Ergonomics into System Design" written by Kenneth R. Boff. It first appeared in the Spring 1990 edition and makes the case that

Failure to adequately consider human capabilities and limitations during the design process is a primary cause of operational deficiencies in military systems and equipment.

These considerations are not always addressed adequately simply because the system designer works in a highly constrained environment where he or she is constantly juggling time, resources, and system performance goals. All too often, human factors practitioners in the design environment are viewed as standing in the way of progress. We are the ones telling the design engineers to go back to the drawing board. It is therefore our responsibil-

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inside:

The Human Systems IAC is a United States Department of Defense Information Analysis Center administered by the Defense Technical Information Center, Ft. Belvoir, VA, technically managed by the Air Force Research Laboratory Human Effectiveness Directorate, Wright-Patterson Air Force Base, OH, and operated by Booz·Allen & Hamilton, Mclean, VA.

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ity to demonstrate the value added in savings in cost and time, and improvements in system performance and safety, that can be achieved by enhancing the performance of the human component. In order that our data be employed

> *...design decision makers must be persuaded or motivated to overcome their ingrained biases against ergonomics.*

The second article, one that appeared in our Summer 1991 issue, "Making Human Factors Truly Human Factors," was written by Alphonse Chapanis. This article takes the field of human factors to task because

> *...we have not clearly established in our minds what human factors is and what it is not.*

His basic position is that—

> *We are all…ultimately concerned with trying to shape the technological world in which we live so that it will better suit us and our needs.*

Thus all the research we do in the name of human factors must be oriented to the design of something. If there are no design implications in our work, or if we fail to make those implications clear to our readers/listeners, then that work

> *…doesn't belong in the human factors literature.*

It dilutes the body of knowledge and worse, our technical jargon confuses practitioners from other disciplines who read our publications looking for help.

The third article is "Human-Centered Design" by William Rouse and appeared in our Fall 1991 edition. It also addresses our role in the design process, starting with the insightful observation that we who preach the value of including the user in design, fail to serve our own customers and users. Rather, we set our sights on bettering the lot of the system end-user alone. This approach, while virtuous and necessary, is not sufficient to making our recommendations acceptable and understandable by design decision-makers. Rouse encourages us to understand

> *…the abilities, limitations, and preferences of those who are expected to employ the products of human factors research and development.…*

If we don't do this, our end-users will never be served.

Finally we have included an article entitled "Naturalistic Decision Making" by Gary Klein and David Klinger that appeared in the Winter 1991 edition. This article also addresses complex decision making, but from the perspective of the decision process itself. Klein and Klinger recognized that decisions are made in the real world (not in the lab) under dynamic and continually changing conditions and severe time pressure, and with ill-defined tasks and significant personal consequences of mistakes. Therefore, a new decision-making model was required to accommodate these real-world issues. It was determined that

> *…under operational conditions, decision makers rarely use analytical methods.…*

Rather, real-world decision makers saw

> *…themselves as acting and reacting on the basis of prior experience; they were generating, monitoring, and modifying plans to meet the needs of the situations.*

These decision-makers were

> *...more interested in finding an action that was 'workable,' 'timely,' and 'cost-effective.'*

This article is more technical in nature than the first three and it may have profound implications on how we might better influence the users of human factors information.

The theme I see emerging from these articles is not the one I first observed when reading them casually. At that point I thought it would be the classic struggle between research and practice. However, upon further reflection, I saw something possibly deeper. The first three are all pieces written to motivate us to enhance the impact of our work on the design of everyday tools and processes. The common theme among them is that all human factors endeavors must be aimed at influencing design, or it is simply not human factors work by definition. If we are to have an impact on the betterment of our society, we must depend on others to take our efforts and apply them in the "natural" world of socio-technical systems design. This situation reflects all the characteristics that

Congratulations to the winners of the *Engineering Data Compendium*. These folks visited the Human Systems IAC booth at the recent Human Factors and Ergonomics Society/International Ergonomics Association combined meeting, July 29 through August 4, 2000, and won copies of the *Compendium*—

Ian Milburn
Brian Peacock
Ken Waugh

Michael Fineberg, Ph.D., is the Chief Scientist for the HSIAC Program Office.

Klein and Klinger have associated with naturalistic decision making (NDM). Perhaps we should assess the NDM model as a possible explanatory framework for the types of decisions that Boff, Chapanis, and Rouse see as the basis of effective design. If it is valid for this application, NMD may predict more salient entry points for the injection of human factors considerations into the design process. We have always thought that the major criterion for the cost-effectiveness of human factors intervention was "the earlier the better." While this may be true, there could be other times during the process when systems designers may be even more approachable and receptive to alternative approaches and the guidance we have to offer.

I hope you enjoy these articles and that you will see other nuances that I have missed. Please feel free to comment on my observations or on the articles themselves. I look forward to hearing from you.■

http://iac.dtic.mil/hsiac

Volume 1, Number 2
Spring 1990

Integrating Ergonomics Into System Design

Kenneth R. Boff

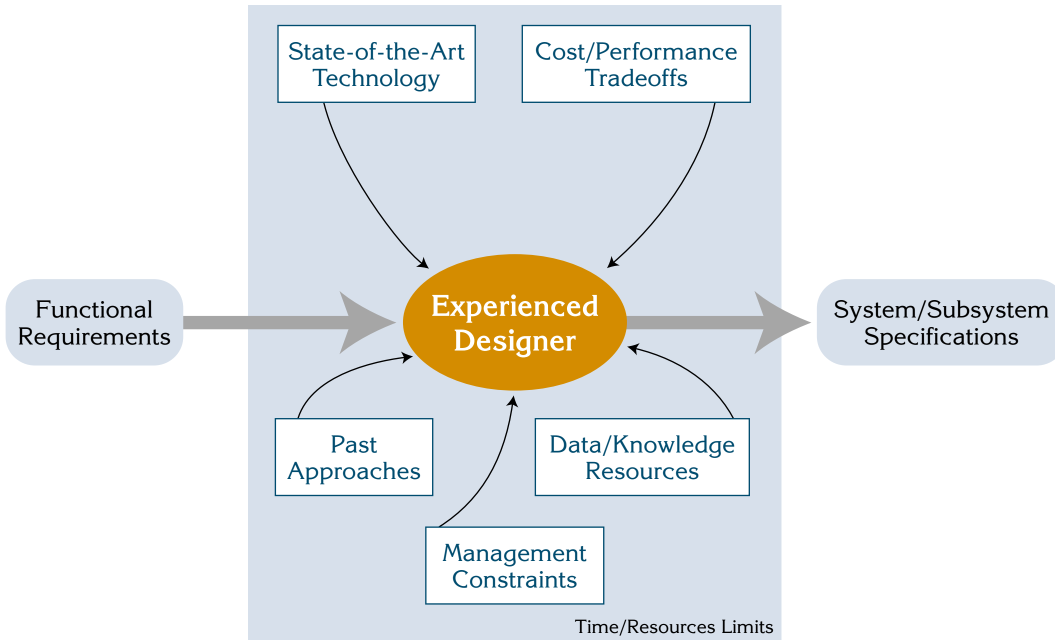

Figure 1. Simplified characterization of the design decision process.

Despite spectacular advances in control, display, and information-handling technologies, the effectiveness of military systems is still inextricably linked to the performance of their human operators and maintainers. Failure to adequately consider human capabilities and limitations during the design process is a primary cause of operational deficiencies in military systems and equipment.

Recognizing this problem, the Department of Defense (DoD) has attempted to integrate ergonomics into the mainstream of system acquisition, design, and engineering to better match system specifications to operator characteristics.

At the forefront of these efforts is the Army's MANPRINT (Manpower and Personnel Integration) program, a comprehensive management and technical initiative to incorporate manpower, personnel, training, and other ergonomics requirements into the materiel acquisition process. Similar programs have recently been inaugurated in the Air Force (IMPACTS, or Integrated Manpower, Personnel, and Comprehensive Training/Safety program) and in the Navy (HARDMAN, or Hardware vs. Manpower program).

Any effort to integrate ergonomics knowledge and resources into design decision making must take account of past failures of ergonomics to be naturally assimilated by the design process and design practitioners. System designers must be motivated to seek and use ergonomics information. This requires an understanding of the "ergonomics of design," that is—

- the nature of design decision making and the context in which it occurs;
- the nature of designers in terms of their basic skills, inclinations, and limitations as architects of design decisions; and
- the nature of potential design information and the way it is used and valued in the design process.

Collectively, these factors determine how effectively ergonomics resources will be integrated into design decisions.

Nature of Design Decision Making

The general goal of system design is to conceive a system whose form and function fulfill defined needs and requirements within prescribed cost, schedule, and material constraints. The process of design decision making in pursuit of this goal (shown schematically in Figure 1, page 4) is best represented as a subjective integration of information and experience, limited by available time and resources. It is an iterative process, recurring throughout all stages of design, and may involve different individuals or groups in the role of designer at different times.

The pressures of tight schedules and limited resources typical in system design drive designers to bias decisions and tradeoffs toward reducing uncertainty and risk. As a result, few new designs for complex systems represent original solutions, which may depend on untested approaches or new technology. Rather most new designs are adaptations or variants of existing designs.

This strong dependence on prior designs as baselines makes it unlikely that designers will seek additional information beyond that viewed as sufficient to meet requirements. In other words, if ergonomics considerations are not embedded in the baseline design, such information is unlikely to be invoked unless it is specifically required and paid for. The scarcity of existing system baselines with a solid ergonomics foundation represents an obstacle to integrating ergonomics information into new systems.

Design effectiveness depends on the information factored into design decisions. Decisions made without considering potentially leveraging information may not be optimal and collectively may undermine system functioning. One way to improve design effectiveness is to make ergonomics information more accessible to designers so it can be incorporated into design decision making more efficiently. Ironic as it seems, however, this task is hampered by the fact that designers are already deluged by too much potentially relevant information competing for their time and attention. If ergonomics information is to be considered adequately in design, a strategy is needed to make ergonomics data more competitive with other technical information in capturing the attention of designers.

The Nature of Designers

Who is the Designer? The design of complex military systems typically involves a large number of individuals, usually from many different organizations, who make decisions that determine the form and functionality of a given design. Though one might expect designers to constitute an easily recognizable, titled group of professionals, design decision making in system acquisition typically involves many individuals who identify with neither the role nor the responsibilities of the designer. This makes it difficult to maintain accountability for an evolving design and to support the design process.

A necessary first step in any strategy for influencing the design process is to identify the key participants in system acquisition and design. These individuals must be educated regarding their roles and responsibilities and must be held accountable for the consequences of their decisions on system effectiveness.

Designer Bias and Inclinations. A significant obstacle to institutionalizing the use of ergonomics information in system acquisition and design is the negative attitude of many engineers and managers toward ergonomics. The perception of many designers and managers is that the *costs* of integrating ergonomics considerations are too high, the *usefulness* of ergonomics design resources is too low, and the probable *gains* are insignificant.

As David Meister has pointed out, it is a common misconception among designers that humans are flexible enough to overcome design inefficiencies. Special attention to ergonomics considerations is therefore deemed unnecessary. Besides, it is argued, "good" engineers already take adequate account of the operator in system design.

If human performance data are to receive equal consideration with other technical information during design, then design decision makers must be persuaded or motivated to overcome ingrained biases against ergonomics.

Cost/Value Considerations in Information Use

In the design process, information is sought and used on the basis of its anticipated utility in making decisions, fulfilling requirements, or meeting system goals. Given the serious constraints of time and resources typically associated with the design of complex military systems, decision making is, by necessity,

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biased towards minimizing costs and maximizing benefits.

The benefits and costs associated with a design decision are linked to the *usefulness* and *usability* of the information factored into it. Information is "useful"

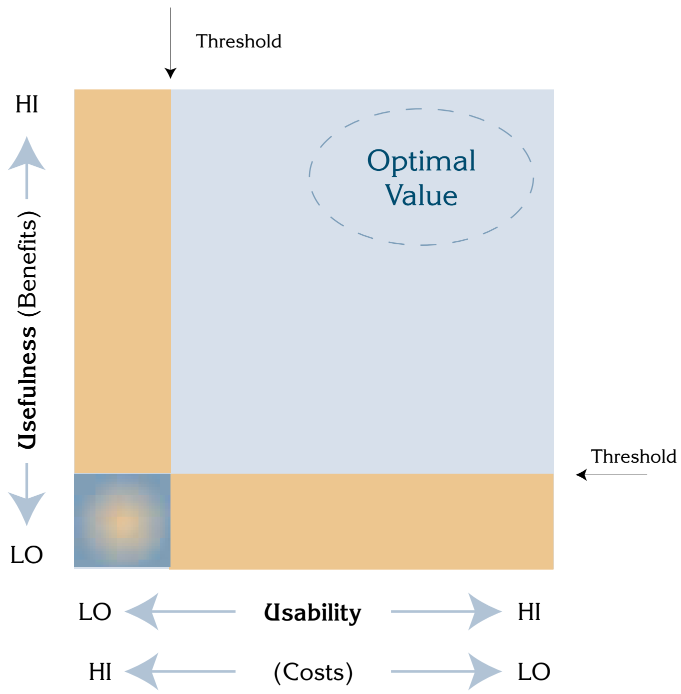

Figure 2. Relation between the usefulness and usability of technical information. Shaded arrows show the minimum acceptable levels below which information will not be used; dotted box indicated the region in which information is likely to have greatest value.

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This article is adapted from "Meeting the Challenge: Factors in the Design and Acquisition of Human-Engineered Systems," in H. R. Booher (Ed.), MANPRINT: An Approach to Systems Integration *(Van Nostrand Reinhold, Spring 1990) and is reprinted with permission of the publisher.*

to a given decision if it confers some advantage or benefit. The use of information may also exact costs, in terms of the time and effort required to find, interpret, and apply the information in a given situation. Information is "usable" when these costs are low.

Figure 2 illustrates the underlying benefit-to-cost relationship between the usefulness and usability of technical information. Information should have optimal value or worth when both its usefulness and its usability are high (i.e., the benefits of use are great and the costs of use are low).

In the absence of objective measures of value, information is likely to be sought and used based on designers' expectations of its usefulness and usability in a given context. Given the negative bias of many designers and their organizational managers toward ergonomics specifications, the *perceived* value or worth of ergonomics information may at times be lower than its potential value.

Often, this is due to its poor usability. Although the research literature in human perception and performance contains much design-relevant data, the volume and diversity of the available information and the difficulty of interpreting scientific jargon make it hard for designers to find and utilize this information in addressing specific design problems. Thus, the high costs and risks of using such information can outweigh its potential benefits or usefulness in designers' eyes.

Mandating the use of ergonomics information in system design has been viewed as one means of ensuring that information of value is not ignored. However, success in regulating the use of information not generally *perceived* as valuable will ultimately depend on the consequences of nonuse, the likelihood that nonuse will be discovered (i.e., policing and inspection) and the anticipated costs associated with using the information (i.e., its usability).

This cost-benefit perspective on the value of information brings into focus the most critical challenge to institutionalizing the use of ergonomics resources in system design: namely, these resources must be positively valued by design decision makers, and their contribution to achieving system objectives must be fully recognized.

To raise the perceived value of ergonomics information among designers and stimulate the use of this information in the design process, steps must be taken to—

- increase the usability of ergonomics resources by reducing the costs and risks associated with their use;
- educate design decision makers regarding the applicability of ergonomics resources and the benefits of their use; and
- ensure that nonuse carries predictable and measurable consequences, for example, by introducing significant penalties for failure to comply with directives, regulations, and standards.

Conclusion

The design of effective military systems and equipment demands an integrated approach to system development in which the role of the human in training, operations, and maintenance is considered interdependent with the design of system hardware and software. It is the thesis here that enhancing human-system integration in the design of complex systems is itself an ergonomics design problem.

Success in achieving this goal can come only through understanding the process by which design decisions are made, the people who make these decisions, and the way technical information is valued and used in the design process.■

Volume 2, Number 3
Summer 1991

Making Human Factors Truly Human Factors

Alphonse Chapanis

Human factors seems to suffer from a never-ending identity crisis. The root of the problem, it seems to me, is that we have not clearly established in our minds exactly what human factors is, and what it is not. Take a look at the publication called *PsycSCAN: Applied Experimental & Engineering Psychology*, a collection of abstracts published periodically by the American Psychological Association. In one issue of that publication I found these titles under the heading of "Human Factors & Ergonomics"—

- Optical and photoreceptor immaturities limit the spatial and chromatic vision of human neonates
- "Pure alexia" without hemianopia or color anomia
- Detection of visual stimuli after lesions of the superior colliculus in the rat; deficit not confined to the far periphery
- Is obesity an eating disorder?
- Hypnotic susceptibility, visual distraction, and reports of Necker cube reversals

What a hodge-podge of miscellaneous and irrelevant studies all classified under the heading of "Human Factors & Ergonomics"! Lest there be any misunderstanding, I am not criticizing the content of any of these studies. What I deplore is their inclusion in the category of human factors. No wonder people are confused about what we do (See Figure 1)!

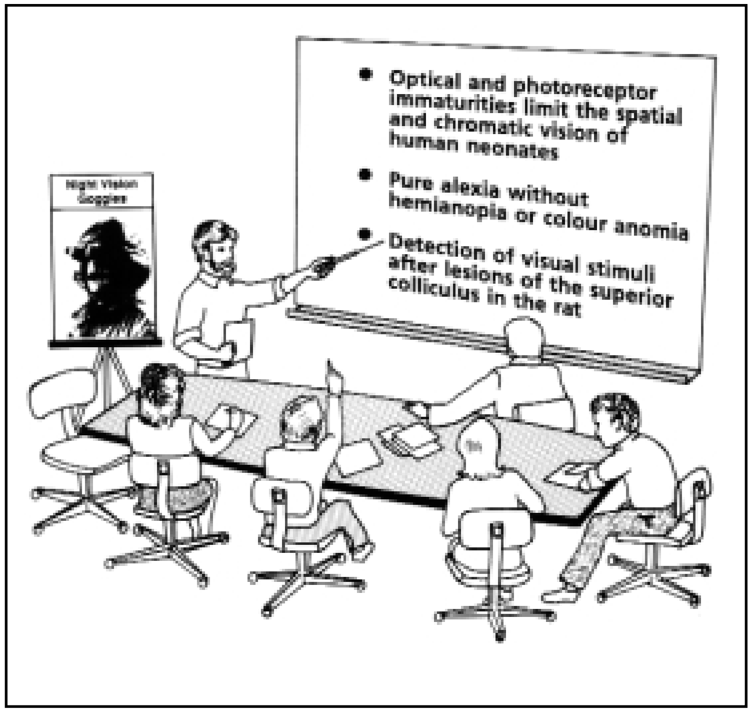

Figure 1. "How will these vision studies help us to improve night vision goggles?"

Let's start with something very basic—Exactly what do we do? Human factors has been defined in several ways. My definition is that—

> *Human factors is a body of knowledge about human abilities, human limitations, and other human characteristics that are relevant to design.*

What we do is human factors engineering, which I define this way—

> *Human factors engineering is the application of human factors information to the design of tools, machines, systems, tasks, jobs, and environments for safe, comfortable, and effective human use.*

I don't want to enter into an extended discussion about the differences between *human factors* and *ergonomics*. Frankly, I think the differences, such as they are, are unimportant and the arguments that have sometimes raged about them have been largely fruitless and a waste of time and energy. Whether we call ourselves human factors professionals or ergonomists is mostly an accident of where we happen to work and where we were trained. We are all—human factors professionals and ergonomists—ultimately concerned with trying to shape the world in which we live so that it will better suit us and our needs. That's the common bond between us and that, in the final analysis, is all that matters.

To return to my definition of human factors and human factors engineering, the significant word in those definitions is design, because it is this that distin-

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guishes us from such purely academic disciplines as psychology, physiology, and anthropology. Our aim is to apply what we know to the design of practical things—things that we have to do or have to use because of our occupations, or things we want to do or want to use because of our inclinations.

If there are design implications in what we do, it is our responsibility to say what they are.... I would endorse a requirement that every manuscript submitted to Human Factors or Ergonomics should have a final section headed Design Implications.

The implications of this point of view are that research, even so-called basic research in human factors, should be oriented toward the design of something. If the findings of that research don't contribute or lead to design recommendations, then the research, no matter how good or how interesting it may be in its own right, has no place in the human factors literature. Let me illustrate with an example.

I read a study in which brain potentials were recorded from a number of locations on the scalp. Subjects were asked to direct their attention, without moving their eyes, to flashing stimuli in one of three locations in the visual field. The evoked brain potentials correlated with the locus of the subject's attention. No design recommendations were made, and frankly, I don't see that any could have been made. It did not belong in the *Human Factors* journal. Articles such as this one communicate no human factors message because they have no such message to communicate. They dilute our literature and confuse those persons who happen to read our journals and who try to infer from them exactly what it is we do.

Another part of the problem is that we often fail to point out the design implications of our research when there are some to be made. I was once giving a lecture to an engineering audience and was talking about sensory thresholds: absolute thresholds, upper thresholds, and JNDs—just noticeable differences. I had just shown some data on typical thresholds for several senses and was starting on my next point when I was interrupted by one of the engineers who asked, "That's all very interesting, but why is it important for me as a design engineer to know all that?" Although my immediate reaction was that he was quibbling, I quickly realized that he was serious. The design implications were obvious to me, but they were not at all obvious to him. I then managed to elaborate by saying that for many machine displays, energy levels had to be intense enough to exceed our absolute thresholds, but not so intense that they exceed our upper thresholds. Moreover, changes in energy levels had to be large enough to exceed our difference thresholds if we were to perceive them. I amplified by using as an example the beam of electrons striking the phosphorescent surface of a computer display terminal. That made sense to him and left him nodding his head in understanding.

The point of that experience is subtle but very important. I wasn't communicating a human factors message. I was talking about some properties of our sensory systems—as sensory systems. In other words, I was talking as a psychologist about what was to me an interesting psychological fact. My audience, however, was made up of engineers who were not interested in becoming psychologists. They had taken the time out of their busy schedules to come to listen to me in the hopes that they could learn something that would help them do their job better, that is, solve problems they had. They did not want to have to digest and deduce for themselves the design implications of what I was giving them. All too often we professionals are guilty of failing to do that.

As one more example, I read a study that investigated the mechanical work and energy transfer both between and within body segments in doing a certain kind of work. The work involved is important because there is so much of it being done these days and because it involves a significant segment of our working population. The study was done with exemplary rigor and the article has tables and charts showing such things as patterns of total energy, and force and velocity curves as a function of movement time. Workers often experience strain and sometimes suffer injuries from doing this work. Yet, after presenting and discussing all their data, the authors made no attempt to tell us what this meant from a design standpoint.

On the basis of their study, how would they recommend redesigning the job to reduce the strains they measured? How could the devices these workers use be redesigned to ease their tasks?

Figure 2. Requiring human factors journals to include a design implications section would enable engineers and designers to make better use of human factors data.

Could any supplementary aids be devised to help workers do their jobs? I realize that the research was not undertaken to answer those specific questions, but surely after all their work, the authors must have formed some ideas about these questions. Even if their design recommendations were tentative, they would at least call attention to some possible ways of improving a stressful and difficult job. As it stands, the study is merely an interesting one on the physiology of movement that happens to have been done in a working environment. There are human factors design implications there, but the authors have made no attempt to communicate them. We cannot expect engineers or designers to read our minds and deduce the design implications of what we have done. If there are design implications in what we do, it is our responsibility to say what they are.

These are only a couple out of many examples I could have used to make my point. To a considerable extent we have justly earned the criticism that we don't communicate our findings to practitioners and designers. This has happened because we sometimes fail to keep in mind the aim of our profession. I repeat: The reason we are in this business is to help design things. The reason we do our research is to find out how to design things better. Having done a study, the authors of it are best able to evaluate what it means for design, and if they claim to be human factors professionals, they have a duty to do just that. If no design implications at all can be drawn from a study, then it doesn't belong in the human factors literature.

I feel so strongly about this matter that I would endorse a requirement that every manuscript submitted to *Human Factors* or *Ergonomics* should have a final section headed "Design Implications" (see Figure 2). If authors can't find any design implications in their work, they should be encouraged to submit their manuscript to other journals.

To sum up—

- If we keep in mind that the only kind of research that belongs in the human factors literature is research that leads to design recommendations
- And if we are always sure to point out the design implications of that research
- We can all help to make human factors truly human factors.■

Alphonse Chapanis, Ph.D., lives near Baltimore, MD. Formerly, he taught at Johns Hopkins University, and served as President of the Society of Engineering Psychologists, the Human Factors Society, and the International Ergonomics Association.

calendar

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Lexington, KY, USA. September 26–28, 2000
SAE's Southern Automotive Manufacturing Conference and Exposition
Contact Society of Automotive Engineers, 400 Commonwealth Drive, Warrendale, PA 15096–0001, USA. Tel: +1–724–776–4841, Fax: +1–724–776–0210, URL: http://www.sae.org

Toulouse, France. September 27–29, 2000
International Conference on Human-Computer Interaction in Aeronautics, HCI–Aero 2000
Contact Ms. Helen Wilson, HCI–Aero 2000 Office, European Institute of Cognitive Sciences and Engineering (EURISCO), 4 Avenue Edouard Belin, 31400 Toulouse, France. Tel: +33–5–62–17–38–38, Fax: +33–5–62–17–38–39, E-mail: wilson@onecert.fr, URL: http://www-eurisco.onecert.fr/

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Reno, NV, USA. October 9–11, 2000
SAFE Association 38th Annual Symposium
Contact SAFE Association, 107 Music City Circle, Suite 112, Nashville, TN 37214, USA. Tel: +1–615–902–0056, Fax: +1–615–902–0077, E-mail: safe@usit.net, URL: http://safeassociation.org/contact.htm

Dayton, OH, USA. October 10–12, 2000
National Aerospace and Electronics Conference, NAECON 2000
Contact Dr. D. W. Repperger, Technical Program Chair, NAECON 2000, 833 Blossom Heath Road, Dayton, OH 45419–1102, USA. Tel: +1–937–255–8765, E-mail: d.repperger@ieee.org, URL: http://www.naecon.org

Savannah, GA, USA. October 15–19, 2000
Human Performance, Situation Awareness and Automation: User-Centered Design for the New Millennium
Contact Dr. David Kaber, Department of Industrial Engineering, PO Box 9542, Mississippi State University, MS 39762, USA. E-mail: kaber@engr.msstate.edu. Or contact Dr. Mica Endsley, SA Technologies, Inc., 4731 East Forest Peak, Marietta, GA 30066, USA. E-mail: mica@satechnologies.com, URL: http://www.ie.msstate.edu/hpsaa/index.html

Edinburgh, Scotland. October 25–27, 2000
Third International Conference on Engineering Psychology and Cognitive Ergonomics
Contact Dr. Don Harris, Human Factors Group, College of Aeronautics, Cranfield University, Cranfield, Bedford MK43 0AL, UK. Tel: +44–1234–750111, ext. 5196, Fax: +44–1234–750192, E-mail: icep@cranfield.ac.uk, URL: http://www.cranfield.ac.uk/coa/coa_conf.htm

# of events

Look for the Human Systems IAC exhibit at these meetings!

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El Paso, TX, USA. November 6–9, 2000

45th Biennial Meeting of the U.S. Department of Defense Human Factors Engineering Technical Advisory Group

Contact Ms. Sheryl Cosing, 10822 Crippen Vale Court, Reston, VA 20194, USA. Tel: +1–703–925–9791, Fax: +1–703–925–9644, E-mail: sherylynn@aol.com, URL: http://dticam.dtic.mil/hftag/ *Meeting is open to all government personnel and others by specific invitation*

Yellow Springs, OH, USA. November 14–16, 2000

Essentials of Anthropometry

Contact Anthrotech (formerly Anthropology Research Project, Inc.), 503 Xenia Avenue, Yellow Springs, OH 45387, USA. Tel: +1–937–767–7226, Fax: +1–937–767–9350, E-mail: belva@anthrotech.net, URL: http://www.anthrotech.net

London, England. November 16–17, 2000

Virtual Reality—Breaking Into the Mass Market

Contact Ms. Hannah Sanders, Access Conferences International, 22 Albert Embankment, London SE1 7TJ, England. Tel: +44–20–7840–2700, Fax: +44–20–7840–2701, URL: http://www.access-conf.com/TB112/

Orlando, FL, USA. November 27–30, 2000

Interservice/Industry Training, Simulation, and Education Conference (I/ITSEC 2000)

Contact Ms. Barbara McDaniel, National Training Systems Association, One Colonial Place, 2111 Wilson Boulevard, Suite 400, Arlington, VA 22201–3061, USA. Tel: +1–703–247–2569, Fax: +1–703–243–1659, E-mail: bmcdaniel@ndia.org, URL: http://www.iitsec.org

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New Orleans, LA, USA. August 5–10, 2001

HCI International 2001. 9th International Conference on Human-Computer Interaction

Contact Kim Gilbert, School of Industrial Engineering, Purdue University, 1287 Grissom Hall, West Lafayette, IN 47907–1287, USA. Tel: 1–765–494–5426, Fax: 1–765–494–0874, URL: http://hcii2001.engr.wisc.edu

Volume 2, Number 4
Falls 1991

Human-Centered Design:
Creating Successful Products, Systems, and Organizations

William B. Rouse

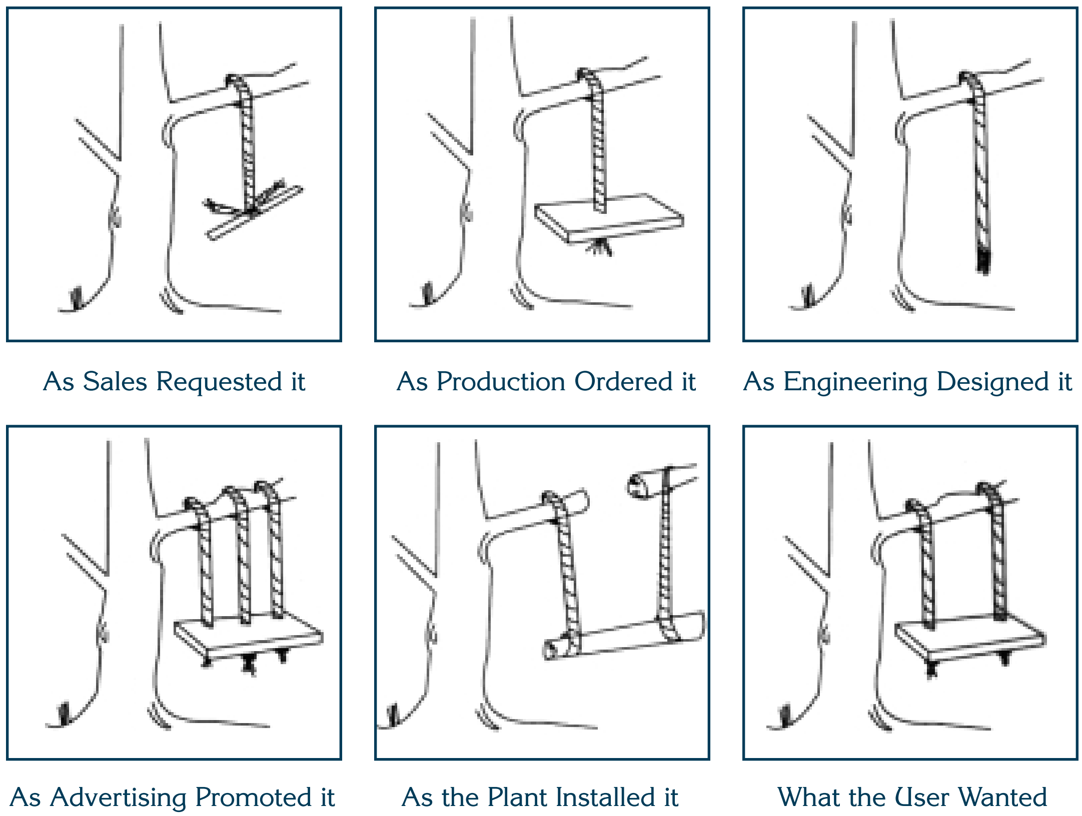

Figure 1. Problems in design.

Everyone wants new products and systems to be user-friendly, user-centered, and ergonomically designed. Everyone endorses these goals. However, as illustrated in Figure 1, many products and systems fall far short of achieving them. Why?

One answer is that human factors concepts, principles, and methods are not sufficiently advanced to meet this need. However, this is only a partial explanation. The fact is that most currently available concepts, principles, and methods have relatively little impact on product and system design. Clearly, therefore, more unused results will not improve the situation.

Thus, the question shifts to the reasons why current concepts, principles, and methods do not impact design. The answer lies in understanding the human factors of design—in other words, understanding the abilities, limitations, and preferences of those who are expected to employ the products of human factors research and development (R&D).

The Nature Of Design

To understand the human factors of design, we must focus on the engineering functions within industrial and governmental enterprises responsible for developing products and systems. The necessary understanding cannot be found within aircraft cockpits or maintenance depots. The people who should be studied are designers and managers, not pilots and maintainers. Several studies of the human factors of design have been performed (e.g., Rouse & Boff, 1987; Rouse, Cody, & Boff, 1991). These studies used interviews, questionnaires, and observational methods involving 240 individuals, roughly half of whom were from industry and half from government.

Designers spend their time in both group and individual activities. For journeymen and seasoned designers, the time allocation is typically 30 percent in group activities and 70 percent in individual activities. Junior designers spend more time in group activity for the purpose of learning. Very senior designers spend more time in group activity, serving as coaches and mentors.

The design group or team has several roles. The group is usually involved with decomposing the statement of work or other descriptions of objectives, requirements, and specifications. Based on this decomposition, the group will set technical goals, as well as allocations of person-hours and schedule, for members of the group. Pursuit of these technical goals is predominantly an individual activity. The group subsequently reviews the results of these individual efforts.

The organization, both of the company and the marketplace, strongly affects both group and individual activities. Company policies and procedures directly influence activities. Success criteria and reward mechanisms, both internal and external to the company, affect motives and values. Corporate and market cultures influence, for example, relative weightings on performance, cost, and quality.

Thus, design involves a complex social and organizational network within which designers and managers seek information, formulate problems, synthesize and integrate solutions, advocate positions, and negotiate compromises. Within this often chaotic world, little time is devoted to seeking human factors concepts, principles, and methods.

Human-Centered Design

What designers need are methods and tools that help them succeed in complex environments such as described above. Recognition of this need led to the development of a concept called human-centered design (Rouse, 1991). Succinctly, human-centered design is a process of ensuring that the concerns, values, and perceptions of all stakeholders in a design effort are considered and balanced.

Thus, human-centered design focuses on stakeholders, not just users. To illustrate, pilots as users of aircraft cockpits are important stakeholders. However, pilots do not build, buy, regulate, or maintain aircraft. There are many more stakeholders in aircraft than just pilots, and the concerns, values, and perceptions of all these stakeholders should be addressed.

We have found that the seven issues listed in Figure 2 are formed by combining the interests of all stakeholders. Human-centered design involves pursuing these issues starting at the top. Thus, the last concern is "Does it run?" while the first concern is "What matters?" or "What constitutes benefits and costs?"

Viability	→	Are the benefits of system use sufficiently greater than its costs?
Acceptance	→	Do organizations/individuals use the system?
Validation	→	Does the system solve the problem?
Evaluation	→	Does the system meet requirements?
Demonstration	→	How do observers react to the system?
Verification	→	Is the system put together as planned?
Testing	→	Does the system run, compute, etc,?

Figure 2. Design issues.

If the issues in Figure 2 were each pursued independently, as if they were ends in themselves, the costs of design would be untenable. However, each issue is important and should not be neglected. What is needed, therefore, is an overall approach to design that balances the allocation of resources among the issues of concern at each stage of design. This can be accomplished by viewing design as a process involving the four phases shown in Figure 3.

The naturalist phase involves understanding the domains and tasks of users from the perspective of individuals, the organization, and the environment. The focus is on understanding the nature of viability, acceptability and validity in the domain for which the product or system is targeted.

The marketing phase involves introducing product and system concepts to potential customers, users, and other stakeholders. Their reactions are needed relative to viability, acceptability, and validity. In other words, one wants to determine whether a product or system concept is perceived as solving an important problem, solving it in an acceptable way, and solving it at a reasonable cost.

The engineering phase concerns trading off conceptual functionality and technological reality. As indicated in Figure

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3, technology development will usually have been pursued prior to and in parallel with the naturalist and marketing phases. In the engineering phase, one becomes very specific about how desired functionality is to be provided, what performance is possible, and the time and dollars necessary to provide it. In this process, evaluation, demonstration, verification, and testing are pursued.

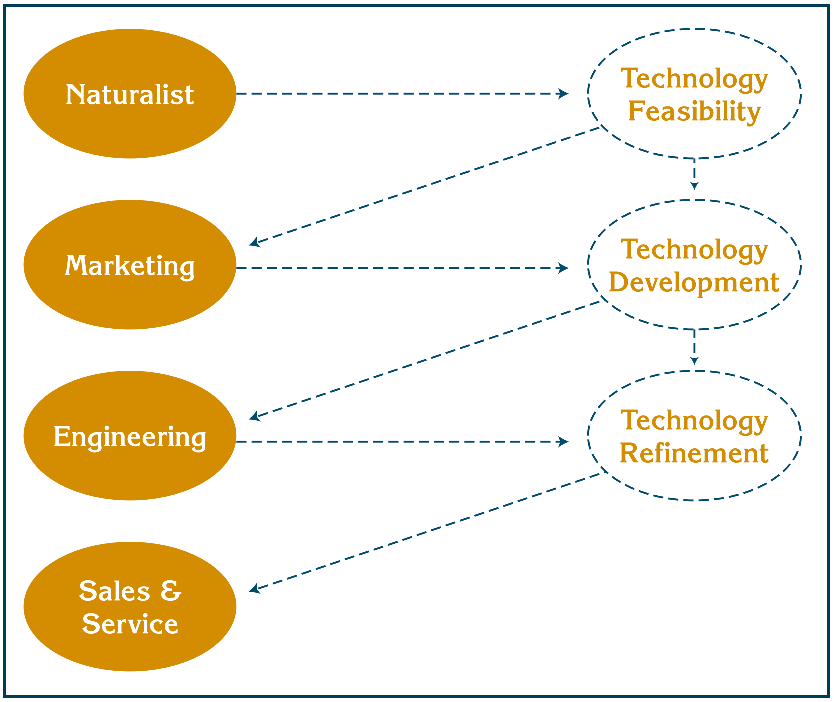

Figure 3. A framework for design.

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In the sales and service phase, one follows the product system into service to gain closure on viability, acceptability, and validity. Implementation problems are solved during this phase. Further, relationships are maintained and new opportunities recognized. This typically expedites the next naturalist and marketing phases.

The human-centered design methodology tersely outlined in this section potentially enables creation of products and systems that are user friendly, user centered, ergonomically designed, and much more. For this potential to be fully realized, the human-centered concept must be expanded.

The Human-Centered Enterprise

The methodology discussed in the last section provides the technical basis for human-centered design. Also required, however, is an appropriate managerial basis. Traditionally, the three pillars of management are planning, organization, and control. Thus, the human factors of management must address human abilities, limitations, and preferences in these activities.

Studies of management of design in particular, and technology-based enterprises in general, led to the concept of human-centered planning, organization, and control (Rouse, 1992). More specifically, the concern was with how enterprises should be designed to best support development, marketing, and service of human-centered products and systems.

The resulting approach to management includes a variety of elements. For example, methods of planning, organization, and control are simplified and streamlined to emphasize usability and usefulness. As another illustration, explicit models of the enterprise's functioning are developed. Training is provided to ensure that these models are shared by all stakeholders within the enterprise.

The concept of a human-centered enterprise is important in that it enables, perhaps even empowers, designers to pursue human-centered design of products and systems. Consequently, it is not a matter of management simply allowing human-centered design; it is important for management to extol this approach.

Summary

Human factors professionals often view themselves as advocates of end users—for example, aircraft pilots. They research pilots' abilities, limitations, and preferences and develop end user-centered concepts, principles, and methods. Unfortunately, however, they typically ignore their own customers and their own users. They concern themselves little with the usefulness and usability of the products of human factors R&D. Consequently, human factors often fails to have an impact. However, by considering the human factors of design, as well as the human factors of management, it is quite possible to provide concepts, principles, and methods that will be embraced and, subsequently, provide the intended benefits to end users.■

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Naturalistic Decision Making

Figure 1. Four-alarm fire in St. Joseph Hall at the University of Dayton, Dayton, Ohio, on December 22, 1987.

Gary Klein and David Klinger

The past five years have seen the development of a new model for understanding how people make decisions in real-world settings. Naturalistic decision making is an attempt to understand how humans actually make decisions in complex real-world settings, such as fire fighting (see Figure 1). This work has focused on situations marked by key features as seen in Table 1. These include dynamic and continually changing conditions, real-time reactions to these changes, ill-defined tasks, time pressure, significant personal consequences for mistakes, and experienced decision makers. These task conditions exist in operational environments associated with crew systems, so it is essential to determine how people handle these conditions.

Previous models of decision making were limited in their ability to encompass these operational features. Classical approaches to decision making, such as Multi-Attribute Utility Analysis (MAUA) and Decision Analysis, prescribe analytical and systematic methods to weigh evidence and select an optimal course of action. MAUA decision makers are encouraged to generate a wide range of options, identify criteria for evaluating them, assign weights to the evaluation criteria, rate each option on each criterion, and tabulate the scores to find the best option. Decision Analysis is a technique for constructing various branches of responses and counter-responses and postulating the probability and utility of each possible future state, to calculate maximum and minimum outcomes.

On the surface these strategies may seem adequate, yet they fail to consider some important factors inherent in real-world decisions. Classical strategies deteriorate when confronted with time pressure. They simply take too long. Under low time pressure, they still require extensive work and they lack flexibility for handling rapidly changing conditions. It is difficult to factor in ambiguity, vagueness, and inaccuracies when applying analytical methods. Another problem is that the classical methods have primarily been developed and evaluated using inexperienced subjects, typically college students.

A group of decision researchers is trying to derive models that describe how experienced decision makers actually function. Rasmussen (1985) used protocols and critical incident interviews to study nuclear power plant operators. He has a three-stage typology of skills (sensorimotor, rule-based, and knowledge-based) which highlights how differential expertise creates differences in decision strategy. Hammond, Hamm. Grassia, and Pearson (1987) studied highway engineers and found that intuitive decision strategies were more effective for tasks

Table 1. Features of Natualistic Decision Making

1. Ill-defined goals and ill-structured tasks
2. Uncertainty, ambiguity, and missing data
3. Shifting and competing goals
4. Dynamic and continually changing conditions
5. Action-feedback loops (real-time reactions to changed conditions)
6. Time stress
7. High stakes
8. Multiple players
9. Organizational goals and norms
10. Experienced decision makers

such as judging aesthetic qualities of a road, while analytical strategies were more valuable for tasks such as estimating amount of traffic. Pennington and Hastie (in press) studied jury deliberation as a complex decision task and found that the jurors attempted to fit all the evidence into a coherent account of the incident. Their assessment was then based on this account or story rather than on likelihood judgments of the evidence introduced The jurors focused on whether the prosecution's or defense's story was more coherent. The work of Noble (in press) with Naval Command-and-Control officers and Lipshitz (in press) with infantry soldiers, has generated the same conclusions—under operational conditions, decision makers rarely use analytical methods and nonanalytical methods can be identified that are flexible, efficient, and effective.

Our work shows how people can make effective decisions without performing analyses. For several years, we have studied command-and-control decision making and have generated a recognitional model of naturalistic decision making. We began by observing and obtaining protocols from urban foreground commanders (FGCs) who are in charge of allocating resources and directing personnel. We studied their decisions in handling non-routine incidents during emergency events. Some examples of these types of decisions included whether to initiate search and rescue, whether to initiate an offensive attack or concentrate on defensive precautions, and where to allocate resources.

The FGCs' accounts of their decision making did not fit into a decision-tree framework. The FGCs argued that they were not "making choices," "considering alternatives," or "assessing probabilities." They saw themselves as acting and reacting on the basis of prior experience; they were generating, monitoring, and modifying plans to meet the needs of the situations. We found no evidence for extensive option generation. Rarely were even two options concurrently evaluated. We could see no way in which the concept of optimal choice might be applied. Moreover, it appeared that a search for an optimal choice could stall them long enough to lose control of the operation altogether. The FGCs were more interested in finding an action that was "workable," "timely," and "cost effective."

Nonetheless, the FGCs were clearly encountering choice points during each incident. They were aware that alternative courses of action were possible, but insisted that they rarely deliberated about the advantages and disadvantages of the different options. Instead, the FGCs relied on their ability to recognize and appropriately classify a situation. Once they knew it was "that" type of case, they usually also knew the typical way of reacting to it. Imagery might be used to "watch" the option being implemented, to search for flaws, and to discover what might go wrong. If problems were foreseen, the option might be modified or rejected altogether and the next most typical reaction explored. This mental search continued until a workable solution was identified.

We have described these strategies as a Recognition-Primed Decision (RPD) model (Klein 1989). For this fireground task environment, a recognitional strategy appears highly efficient. The proficient FGCs we studied used their experience to generate a workable option as the first to consider. If they had tried to generate a large set of options, and then systematically evaluated these, it is likely that the fires would have gotten out of control before they could make any decisions.

Three examples of the RPD model are presented in Figure 2 (page 18). The simplest case is one in which the situation is recognized and the obvious reaction is implemented. A somewhat more complex case is one in which the decision maker consciously evaluates the reaction, typically using imagery to uncover

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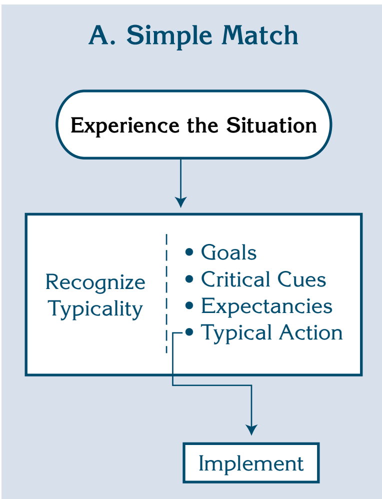
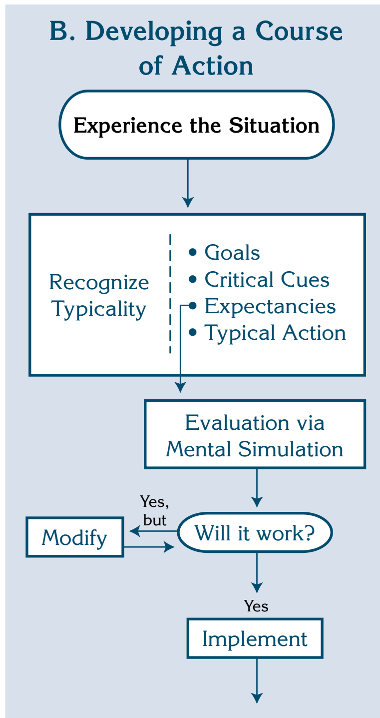
problems prior to carrying it out. In the most complex case, the evaluation reveals flaws requiring modification, or the option is judged inadequate and rejected in favor of the next most typical reaction.

The model is characterized by the following features, which are summarized in Table 2.





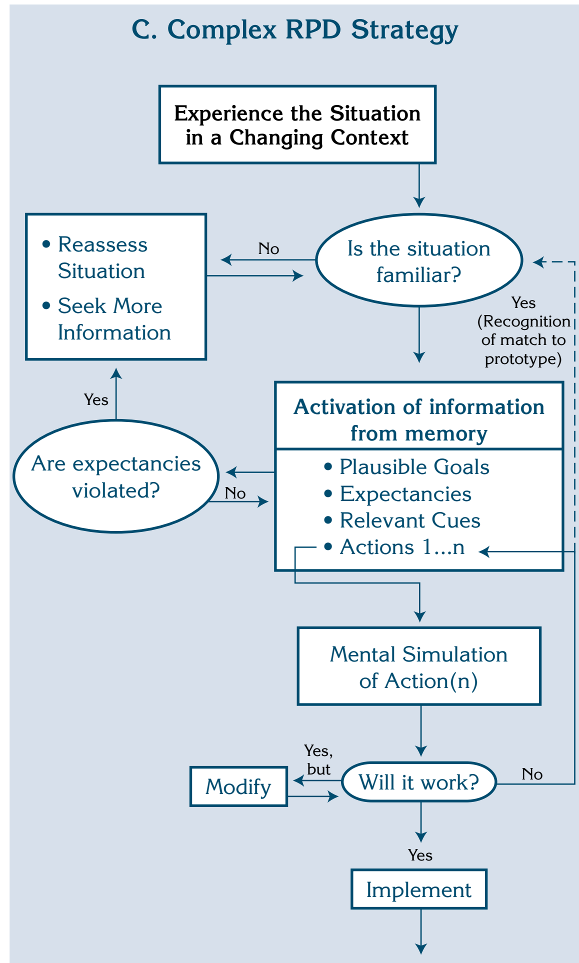


Figure 2. Recognition-rimed Decision Model

- Situational recognition allows the decision maker to classify the task as familiar or prototypical.
- The recognition as familiar carries with it recognition of the following types of information: plausible goals, cues to monitor, expectancies about the unfolding of the situation, and typical reactions.
- Options are generated serially, with a very typical course of action as the first one considered.
- Option evaluation is also performed serially to test the adequacy of the option, and to identify weaknesses and find ways to overcome them.
- The RPD model includes aspects of problem solving and judgment along with decision making.
- Experienced decision makers are able to respond quickly, by using experience to identify a plausible course of action as the first one considered rather than having to generate and evaluate a large set of options.
- Under time pressure, the decision maker is poised to act while evaluating a promising course of action, rather than paralyzed while waiting to complete an evaluation of different options. The focus is on acting rather than analyzing.

We do not propose the RPD model as an alternative to analytic approaches. Rather, we postulate that recognitional and analytical decision strategies occupy opposite ends of a decision continuum similar to the cognitive continuum described by Hammond et al. (1987). At one extreme are the conscious, deliberated, highly analytic strategies such as MAUA and Decision Analysis. Slightly less analytic are noncompensatory strategies such as elimination-by-aspects. At the alternate end of the continuum are Recognition-Primed Decisions (RPD), which involve non-optimizing and non-compensatory strategies and require little conscious deliberation. RPDs are marked by an absence of comparison among options. They are induced by a starting point that involves recognitional matches that in turn evoke generation of the most likely action.

We have tested applications of the model in a variety of tasks and domains, including fireground

Table 2. Key Features of Recognition-Primed Decision (RPD) Model

1. First option is usually workable NOT random generation and selective retention
2. Serial generation/evaluation of options NOT concurrent evaluation
3. Satisficing NOT optimizing
4. Evaluation through mental simulation NOT MAUA, Decision Analysis, or Bayesian statistics
5. Focus on elaborating and improving options NOT choosing between options
6. Focus on situation assessment NOT decision events
7. Decision Maker primed to act NOT waiting for complete analyses

command, battle planning, critical care nursing, corporate information management, and chess tournament play. These studies have shown good support for the validity and utility of the model presented in Figure 2 as it applies to individual decision makers. Our coding was evaluated as having 87% to 94% inter-rater reliability.

What are the implications of the naturalistic decision-making approach? A workshop in Dayton, Ohio, in Fall 1989, took stock of the current state of knowledge and explored implication and future research directions. Attending were researchers who had been active in naturalistic decision making, including 31 professionals who represented decision research being conducted by the military, NASA, private firms, and academic institutions The domains studied spanned tactical operations, medical decision making, weather forecasting, nuclear power plant control, and executive planning among others. This workshop was sponsored by the Army Research Institute (ARI) which began a research program in 1985 on Planning, Problem Solving, and Decision Making. The goal of this program is to make decision research more relevant to the needs of the applied community.

The Dayton workshop enabled researchers, working with different domains and paradigms, to find commonalities and to identify remaining questions. The workshop succeeded in identifying the favors of greatest interest for generalizing to operational settings. The participants documented limitations of classical decision theory, and explored opportunities for using nonanalytical models to develop better training programs and decision support systems. The participants also contributed to a book, *Decision making in action: Models and methods*, edited by Gary Klein, Judith Orasanu, and Roberta Calderwood (expected date of publication, 1991). It will be available through Ablex Publishing Corporation, 355 Chestnut Street, Norwood, NJ, 07648.■

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